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Once more on the bound on ν_τ magnetic moment from L3 data

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Abstract

We show that recently announced strong bound on μ_{ν_τ} can not be justified, and confirm original L3 result.

1 Introduction

Experimental bounds on the magnetic moment of the τ-neutrino is much weaker than bounds on magnetic moments of electron and muon neutrinos:

$$\mu_{\nu_e} < 1.8 \times 10^{-10}\,\mu_B; \tag{1}$$
$$\mu_{\nu_\mu} < 7.4 \times 10^{-10}\,\mu_B; \tag{2}$$
$$\mu_{\nu_\tau} < 4 \times 10^{-6}\,\mu_B; \tag{3}$$
$$\mu_{\nu_\tau} < 5.4 \times 10^{-7}\,\mu_B; \tag{4}$$

where bound (3) comes from analysis of the e^+e^- annihilation to γ+nothing at low energies [1], and bound (4) comes from beam-dump experiment [2]. New bound was obtained recently by L3 collaboration from analysis of the e^+e^- annihilation at the Z resonance. Search for energetic single photon production in Z decays leads to the following bound [3]:

$$\mu_{\nu_\tau} < 3.3 \times 10^{-6}\,\mu_B. \tag{5}$$

However, in paper [4] new analysis of L3 data was performed, and much more stringent bound was announced:

$$\mu_{\nu_\tau} < 1.14 \times 10^{-9}\, \mu_B, \tag{6}$$

which(if correct) will put bound on μ_{ν_τ} close to that for electron and muon neutrinos. Trying to reproduce result [4] we fail and confirm bound (5) obtained originally by L3 collaboration.

2 Discussion

In paper [4] the following relation was used:

$$\mathcal{L}_I = -\frac{1}{2}\mu_\nu\, F_{\mu\nu}\, \bar{\nu}\Sigma^{\mu\nu}\nu - Z_\mu\, \bar{\nu}\gamma^\mu \left(g_V - \gamma_5\, g_A\right)\nu, \tag{7}$$

$$\mu_\nu \equiv \frac{\epsilon_6}{\sqrt{2}v}, \qquad g_V = g_A \equiv \frac{g}{4c_w} = \frac{e}{4c_w s_w}, \tag{8}$$

where v is the Higgs boson vacuum expectation value, $v \approx 246\, GeV$. For the partial decay width $Z \to \nu\bar{\nu}\gamma$ from (7) it was obtained:

$$\frac{d\Gamma^{(a)}}{dx} = \frac{\epsilon_6^2\left(g_V^2 + g_A^2\right)M_Z^3}{72\pi^3 v^2} x\left(3\left(1-2x\right) + x^2\right). \tag{9}$$

In paper [4], an additional effective $Z\nu\bar{\nu}\gamma$ vertex was introduced, leading to the following partial decay width $Z \to \nu\bar{\nu}\gamma$ (there is no interference with μ_ν induced decay):

$$\frac{d\Gamma^{(b)}}{dx} = \frac{\epsilon_8^2 M_Z^5}{18\pi^3 v^4} x^3\left(1-x\right). \tag{10}$$

Following the strategy outlined by Maya et al., we perform integration of these equations to obtain the width for $Z \to \nu\bar{\nu}\gamma$ decay. The integration must be performed for x ranging from $\frac{1}{4}$ (the L3 collaboration required the photon energy to be greater than half the beam energy [3]) and $\frac{1}{2}$ (the maximum value for the photon energy is reached when the photon direction is opposite to the direction of the two neutrinos, and equals $\frac{M_Z}{2}$). We find:

$$\Gamma^{(a)} = \frac{\epsilon_6^2\left(g_V^2 + g_A^2\right)M_Z^3}{72\pi^3 v^2} I, \tag{11}$$

$$I = \int_{\frac{1}{4}}^{\frac{1}{2}} x\left(3\left(1-2x\right)+x^2\right)dx = \frac{79}{1024} \approx 0.077 \tag{12}$$

from eq. (9), and

$$\Gamma^{(b)} = \frac{\epsilon_8^2 M_Z^5}{18\pi^3 v^4} J, \tag{13}$$

$$J = \int_{\frac{1}{4}}^{\frac{1}{2}} x^3\left(1-x\right)dx = \frac{11}{1280} \approx 0.0086 \tag{14}$$

from eq. (10). We now remind that the L3 collaboration data sample corresponds to $N_{Z\to \text{had}} = 3.3\times 10^6$ hadronic Z decays. The $Z\to$ hadrons decay width can easily be evaluated neglecting strong interactions between quarks in the final state and considering $Z\to q\bar{q}$ decay at tree level:[1]:

$$\Gamma_{Z\to q\bar{q}} = \frac{M_Z^3}{48\pi v^2}\left[\left(C_V^q\right)^2+\left(C_A^q\right)^2\right], \tag{15}$$

$$C_A^u = 1, \quad C_V^u = 1-\frac{8}{3}s_w^2, \tag{16}$$

$$C_A^d = 1, \quad C_V^d = 1-\frac{4}{3}s_w^2. \tag{17}$$

Only five quark flavours (u, c and d, s, b) give contribution to (15), so we have:

$$C = 3\left\{2\left[(C_V^u)^2+(C_A^u)^2\right]+3\left[\left(C_V^d\right)^2+\left(C_A^d\right)^2\right]\right\}\approx 20.4, \tag{18}$$

$$\Gamma_{Z\to \text{had}} = \frac{M_Z^3}{48\pi v^2}C \approx 1.69\ GeV, \tag{19}$$

in good agreement with the experimental value $1.7407\pm 0.0059\,GeV$ reported by the Particle Data Group. The number of expected $Z\to\nu\bar{\nu}\gamma$ events for the considered sample is then:

$$N^{(a)} = \frac{\Gamma^{(a)}}{\Gamma_{Z\to \text{had}}}N_{Z\to \text{had}} = \frac{\alpha I}{3\pi s_w^2 c_w^2 C}\,N_{Z\to \text{had}}\,\epsilon_6^2 \approx 54\,\epsilon_6^2, \tag{20}$$

$$N^{(b)} = \frac{\Gamma^{(b)}}{\Gamma_{Z\to \text{had}}}\,N_{Z\to \text{had}} = \frac{8M_Z^2 J}{3\pi^2 v^2 C}\,N_{Z\to \text{had}}\,\epsilon_8^2 \approx 52\,\epsilon_8^2. \tag{21}$$

According to ref. [3], the number of *background* events expected from standard model is ~ 2.4, and the number of events experimentally seen is 2. So ordinary standard model background events completely cover any possible new physics signal, and we can use experimental data only to set an upper bound to the quantities (20) and (21). A rough but simple way to do this is to require the expected signal to be smaller than the observed background; in this way, we obtain a constraint for ϵ_6 and ϵ_8:

$$N^{(a)} < 2 \quad \Rightarrow \quad \epsilon_6 < 0.2, \tag{22}$$

$$N^{(b)} < 2 \quad \Rightarrow \quad \epsilon_8 < 0.2. \tag{23}$$

In expressions (11) and (12) of ref. [4], Maya et al. report constraints which is about 4 order magnitude smaller. It is not clear how they managed to obtain such small values for ϵ_6 and ϵ_8.

[1] At the Z resonance, 1-loop corrections give a contribution of order $\frac{\alpha_s}{\pi}\approx 4\%$; we use parton model calculation instead of experimentally measured $\Gamma_{Z\to \text{had}}$ width to get simple analytical expressions (20) and (21).

The constraint (22) can be translated into an upper bound for the τ-neutrino magnetic monent, by means of eq. (8). In terms of Bohr magneton, we have:

$$\mu_\nu = \frac{\epsilon_6}{\sqrt{2}v}\frac{\mu_B}{\mu_B} = \frac{\epsilon_6}{\sqrt{2}v\frac{e}{2m_e}}\mu_B = \frac{m_e}{v}\frac{\sqrt{2}\epsilon_6}{e}\mu_B. \tag{24}$$

The presence of the factor $\frac{m_e}{v}$ depends essentially on the fact that we have chosen to measure μ_ν in units of Bohr magnetons - which is a quantity strictly related to electron mass - while μ_ν has completely nothing to do with electron properties. So our conclusion is that the factor $\frac{m_e}{v}$ is not related to any mass scale involved in the calculation of μ_ν by means of $SU(2)_L \times U(1)_Y$ invariant quantities (as Maya et al. claimed). This is also clear if we perform numerical substitution in eq. (24) to extract an explicit result: if we assume for ϵ_6 the upper bound of 8.8×10^{-5} trusted by Maya el al., their result $\mu_\nu < 1.14 \times 10^{-9}$ is reproduced, but if we use our constraint (22) we obtain:

$$\mu_\nu < 2 \times 10^{-6}, \tag{25}$$

which nicely coincide with the upper bound found by the L3 collaboration and reported in [3].

3 Conclusions

We have tried to understand the result announced by Maya et al. in ref. [4] for the τ-neutrino magnetic moment, and we found that their result is wrong. Moreover, we conclude that the use of $SU(2)_L \times U(1)_Y$ gauge invariant operators do not improve bound on μ_{ν_τ}, in contrast to what Maya et al. claimed. Our calculations reporduce and confirm the previous bound found by the L3 collaboration.

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